A Critical Discussion of The Efficacy of Using Visual Learning Aids From The Internet To Promote Understanding, Illustrated With Examples Explaining The Daniell Voltaic Cell

Ingo Eilks  
*Universität Bremen, Bremen, GERMANY*

Torsten Witteck  
*Engelbert-Kaempfer-Gymnasium, Lemgo, GERMANY*

Verena Pietzner  
*Universität Koblenz-Landau, Landau, GERMANY*

Received 25 February 2008; accepted 19 April 2008

This paper discusses what chemistry students might see while working with animations found on the Internet and how these electronic illustrations can potentially interact to reinforce rather than resolve misconceptions about chemical principles that a student may possess. The Daniell voltaic cell serves as an example to illustrate the ways in which visual aids can be interpreted differently by different people. Some illustrations seem to represent concepts which have repeatedly been discussed on the base of science education research evidence as typical student misconceptions about chemical concepts. These visual aids seem to embody the actual misconceptions of chemical principles rather than explaining the scientifically accepted chemical concepts behind them. This paper discusses whether such computer simulations are potentially helpful for better understanding, or whether they actually increase the risk of strengthening students’ incorrect interpretations or false ideas about chemical concepts. Implications for structuring and using animations are discussed.

*Keywords:* Chemistry Education, Multimedia Learning, Animations, Misconceptions

**INTRODUCTION**

“WYSIWYG - What you see is what you get” was an innovation in information technology some 15 years ago. Until this shift towards WYSIWYG-technology occurred, cognitive tools like text editors had not been able to accurately depict edited materials on the computer monitor in their real layout while simultaneously working with and altering them. Frequently, this led to various surprises when printing a hardcopy of the material. Today, it is no longer a problem to display correct fonts, page layouts or picture elements on the screen while simultaneously processing documents and files. Moreover, with the modern tools existing today, there is almost no difficulty in creating
pictures, simulations, and visual aids in any form and context we like. Modern computer games beautifully demonstrate the current, cutting-edge breakthroughs in developing illustrations and animated programs.

On a certain level animation technology no longer demands highly specialized programmers. Applications like Macromedia Flash have become easy to use and many curriculum planners and teachers are now able to create animated aids using these tools. This has led to a large increase in the number of animated visual aids on the Internet for a variety of science topics. But the question remains whether all of these animated illustrations are truly useful in supporting learning. Does any given illustration from the Internet provide us with what we really want or need to have? Do illustrations support learning processes simply by showing chemical concepts in an electronically animated format?

The question of whether we get what we see or, perhaps more importantly, what students perceive when watching animations, must be asked from a different point of view. This is because focusing on the use of animated illustrations in education is different than discussing computer games played merely for entertainment. We know from constructivist theories of learning (e.g., Bodner, 1986) that visual aids are not captured in learners’ heads without being filtered and interpreted using the framework of the viewer's preconceptions. We use illustrations in science education in the hope that they will promote a deeper understanding of learning as described, e.g., by Bodner et al. (1986). The central message is that students get interpretations of computer-animated illustrations. We use illustrations in science education in the hope that they will promote a deeper understanding of learning as described, e.g., by Bodner et al. (1986). The central message is that students get interpretations of computer-animated illustrations.

**Learning by visualisation**

Today learning as a whole and so learning with visualisations is generally referred to a constructivist understanding of learning as described, e.g., by Bodner (1986). The central message is that students get information, e.g. via a computer screen, and will construct from this information together with the knowledge they have new ideas and concepts. In his article on constructivist learning, Storck (1995) points out three essentials:

- Concepts, ideas and knowledge that the students bring with them into the classroom have to be taken into account when evaluating, planning and structuring learning processes.
- Provoking cognitive conflicts and their solutions is of high potential value for facilitating a change in student preconceptions into valid scientific concepts.
- It is not necessary that alternative ideas about chemical principles will be replaced by scientific “truths” in all cases. There are situations where it seems to the student do be of more value to retain more naïve ideas or beliefs about scientific processes or theories. One example may illustrate this. In our everyday life, we regularly speak about the consumption of energy. It is clear that we have to support an electronic device by electricity, or a car by gasoline as a source of energy. The correct idea of a change from one form of energy into another under recognition of the principle of Conservation of Energy is not necessary here because we are thinking within this context exclusively on those forms of energy that can be used in our interest in that moment, and maybe on the costs for supplying us with “usable” energy.

Constructivist learning has been one of the leading forces for intensive empirical research into students’ alternate beliefs about chemistry and also into their learning problems. Evidence has been gained in many different fields (e.g., Garnett, Garnett and Hackling, 1995), for example, electrochemistry-respective reviews were given by Garnett and Treagust (1992 a) and de Jong and Treagust (2002). Many of these studies focused on the details of understanding electrochemical cells. For a deeper understanding of this field, additional relevant information also can be obtained from more basic research on the particulate nature of matter or on the theories for understanding electricity (e.g., de Jong and Treagust, 2002).

Constructivist learning seeks to explicitly pinpoint alternate ideas about chemistry and to create learning environments where these alternate beliefs can be discussed and replaced with less naïve and scientific reliable concepts. This can be achieved by provoking a cognitive conflict and then using this conflict to promote a conceptual change (Posner, Strike, Hewson and Gertzog, 1982), e.g. where the naïve ideas can be falsified by the use of experiments. An example may illustrate this. Teachers frequently report that ions within an electrochemical cell are thought by many students to come “out of” the electrode. They then disappear after being uncharged at the electrode. In the students’ minds this is not always connected with a gain or loss in the mass of the two oppositely-charged
chemistry is so difficult to learn (Johnstone, 1991). In
world, a similar approach is not available and this is why
concepts and alternate ideas of the submicroscopic
knowledge of the physical world.

Berzelius were forced to follow in their quest for
experimentation, the same path that Lavoisier, Boyle, or
proposed and then proven or disproven through
experimental nature of science. A hypothesis is
Additionally, such experiments show the hands-on,
experimental nature of science. A hypothesis is
proposed and then proven or disproven through
experimentation, the same path that Lavoisier, Boyle, or
Berzelius were forced to follow in their quest for
knowledge of the physical world.

Unfortunately, this scenario is limited to the
phenomenological level. In most examples focusing on
concepts and alternate ideas of the submicroscopic
world, a similar approach is not available and this is why
chemistry is so difficult to learn (Johnstone, 1991). In
chemistry, we often use models to help us better
understand phenomena at the submicroscopic level.
With improvements in computer technology, it is now
common to use computer-generated animations and
simulations of the submicroscopic world. Such
computer-animated illustrations provide considerable
advantages over static images because they allow us to
visually demonstrate the dynamic nature of the
submicroscopic world.

According to Mayer (2003), students can learn more
profoundly from a multimedia explanation presented in
both words and pictures than in words alone (“the
multimedia effect”). This effect is explained by the dual
coding theory of Pavio (1986) that states that visual and
verbal information in the brain are processed differently
and along distinct channels while the learner creates
separate representations in each channel. These
different codes can interact and promote successful
learning. But, this promising process is not self evident.
Schnitz and Bannert (2003) discuss the fact that
pictures in multimedia learning processes are not
necessarily of benefit to learning in every case. Pictures
can only be understood by semantic processes. Also,
pictorial information is always related to the pre-
knowledge of the learner. Learning effectiveness is
highly dependent on students’ preconceptions.
Therefore, if effective learning should take place
illustrations and visual aids need to be structured to take
account of the learner’s pre-knowledge of a given topic.
This means:

If the learner’s preconceptions are scientifically reliable,
illustrations should confirm and foster them.
If the learner’s preconceptions of a topic are scientifically
unreliable, illustrations should induce a cognitive conflict
which leads to overcoming the formerly-held ideas.

In both cases it is necessary to use illustrations that
are scientifically reliable and that do not demonstrate or
call upon incorrect or conflicting explanations.
Generally, we would think that this could always be
taken for granted, but even static illustrations in school
textbooks do not always meet these criteria (e. g., Eilks,
2003).

The Daniell voltaic cell as example

The Daniell cell is one of the most familiar and easy-
to-use voltaic cells and is therefore the chosen example
for voltaic cells in many science curricula. Nevertheless,
the following discussion is just an exemplary case.
Similar examples could be found for a range of other
science topics.

Because the Daniell cell is an often-discussed topic
in chemical education, many visual aids are available on
the Internet. Appendix 1 lists a number of such
resources for the Daniell cell from different countries.
One of the examples from a German website (Figure 1)
for secondary and tertiary education will be used as our
first example to show the problems in “seeing”
animations which do not “really” animate the science
concept which is commonly accepted within the
scientific community. Some of the other animations in
Appendix 1 are quite better models to explain Daniell’s
voltaic cell in terms of our commonly accepted scientific
view, while others are questionable in a similar way.

What do we see when we look at the five diagrams in
figure 1? The figure illustrates steps in the animation,
and the formation of zinc ions from the zinc electrode
can be recognized. The external electrical circuit is
completed by a salt bridge. Zinc ions are solvated by the
aquesous solution around the anode. Connected to this
process, two electrons are set free. The external
electrical circuit conducts these electrons toward the
copper electrode. The electrons become available for
reducing metal ions at the copper electrode. Copper
ions in the solution move toward the copper cathode
and accept the electrons. Copper atoms are formed and
deposited on the copper electrode. Overall, we see a
flow of electric current, which would be able to power a
small engine.

But is this really what we see? Most of the things
described above cannot, in fact, be seen within the
animation. Most of the steps involved are
interpretations stemming from the pre-knowledge we
possess: They represent rather our teacher’s expert
knowledge of voltaic cells.
What then do we really see? What we see is a zinc electrode. This electrode is represented as a continuum: it does not consist of atoms. If we take into consideration the fact that zinc atoms are larger than the corresponding zinc ions, it is impossible to believe that the zinc electrode consists of zinc atoms. The electrode is thinner than any of the zinc atoms could possibly be. Starting at the zinc electrode, zinc ions move into the solution. The ions either come out of the electrode or from behind it. The ions move into a continuous “grey zone”, which is not involved in the whole process. During the entire reaction there are no changes in the zinc electrode’s mass or size. It is not reduced (see above). Accompanying the appearance of the zinc ions,
two electrons are released. These same two electrons move through an envisioned “electron channel” towards the copper electrode, which is a questionable construct of electric conductivity in metals. Also the copper electrode is represented as an unaffected continuum. A copper ion from the solution moves towards the charged electrode. Together with the disappearance of the two zinc-generated electrons, a copper atom is formed and disappears into or behind the copper electrode. Similarly this second electrode does not change throughout the process. The zinc electrode does not appear to become smaller, nor does the copper electrode appear to get larger. It is obvious that both electrodes have no more in common with the redox reaction than the external wire circuit or the salt bridge. The salt bridge exists, but it is not involved in the dynamics of the process. In interpreting the picture of the external circuit (“the electron channel”) only electrons can be transported. The salt bridge looks the same, since ions seem to be too large for passing the salt bridge. Even the transport

Table 1. Selected results from empirical research about scientifically unreliable concepts from students, with relevance for understanding electrochemical cells

<table>
<thead>
<tr>
<th>Considered ideas</th>
<th>Compromises</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrodes are composed of atoms of zinc or copper, respectively. During the reaction, zinc atoms are changed into ions. The zinc ions are dissolved. Solvated copper ions are changed into copper atoms and form new copper at the copper electrode.</td>
<td>The particles of the solvent are not shown. The level of the solution is sketched, but a grey or colourful sketch of a continuum is not shown. Additional information is available as a pop-up window, where a picture is available showing all particles within both half-cells.</td>
</tr>
<tr>
<td>No particles seem to spontaneously appear from nothing or disappear into nothing. The principles of conservation of mass and the conservation of atoms are considered.</td>
<td>Conductivity of the external electric circuit and the salt bridge is not explicitly shown in the animation. Additional information is available as a pop-up window, where both the processes of conductivity in metals and in electrolytes are explained.</td>
</tr>
<tr>
<td>Chemical change in particles leads to change in the electrodes’ mass and structure. The zinc electrode becomes smaller, the copper electrode becomes bigger.</td>
<td></td>
</tr>
<tr>
<td>There is no visualisation of a flow of electric current only from one half-cell to another.</td>
<td></td>
</tr>
</tbody>
</table>
of charges in electrolytes as a free-flow of electrons is an often-documented misconception among students. …

But why then do we “see” what we believe we see? Our “expert knowledge” leads us to perceive what we wanted to see: An animated illustration of the Daniell cell. Within seconds we reconstruct our knowledge using the impulse of the animated picture to obtain the correct view. The observed content is no longer of interest to us. Unfortunately, we can’t expect the same for our students.

Students’ alternative ideas revisited

![Diagram of the Daniell cell](image)

Figure 2. Draft of an animation on the Daniell cell (Pietzner, Eilks, & Witteck, 2008). Originally produced in German, but an English version is also available.

You may think that our interpretation of the above-discussed animation is much exaggerated. This may be true. One may think this is only a model. Models always use shortcuts and simplifications to represent its target (van Driel and Verloop, 1999). If a model is sufficiently discussed and reflected upon in the classroom, there may no longer be any misunderstandings, but can we be confident in this belief? If we view model-based thinking as a serious task in scientific learning, we need to recognise that the above-mentioned animations are not the models but merely illustrations of the scientific model; it is just a teaching model (Justi and Gilbert, 2002b). The scientific models, or scientific theories, as we may call them, are the ideas behind: The scientific models of particles, atoms and atomic structures, or the model of electron-transfer. Teachers will recognize quite quickly where illustrations and scientifically accepted models depart from one another. This, however, cannot be expected from students. In most cases, students do not have a sufficiently-developed understanding of scientific models and modelling (Grosslight, Unger, Jay and Smith, 1991), unfortunately this may also be true for some teachers (e.g. van Driel and Verloop, 1999; Harrison, 2000; Justi and Gilbert, 2002a and b). In the
same vein, students lack a developed understanding of the processes occurring in the submicroscopic world.

Empirical research has revealed that there are many alternate beliefs that students hold about matter and chemical change. These results consequently suggest many points to keep in mind when viewing animations as a potential, helpful tool for learning. Table 1 gives some selected results, which may be important for understanding the visual representations of the Daniell cell discussed above. However, it is very difficult to create a visual aid both showing the processes within the Daniell cell and also recognizing all the consequences of students’ alternate beliefs. Simplifications appear to be necessary to reach some kind of clarity for the learner. But which kind of simplification is acceptable, and which will only serve to nurture students’ alternate beliefs? Of course, we don’t have a definitive answer. But to start a discussion, figure 2 shows a draft visual aid. Table 2 discusses some results from empirical research which had been taken into consideration, but shows also some compromises.

IMPLICATIONS

Using our criteria, even the second visual aid is far from perfect; even here compromises were necessary. The purpose of this paper is not to explain how a perfect simulation of the Daniell cell should appear. Rather it discusses how difficult it is to create a potentially-helpful visual aid for students to learn chemistry. Our example also shows that it is often easier to make progress by considering the results from empirical research. Another lesson we can derive from the above discussion is that it can be very risky to use information technology and visual aids which have not been thoroughly considered and tested to identify any potential problematic interpretations from the student’s point of view. Animations too often seem to have a greater potential to foster misconceptions than to promote scientific understanding, especially if they are constructed without sufficient reflection on the learners’ perspective and pre-knowledge.

Appendix 1 offers different examples for animations of Daniell’s voltaic cell in different languages. If we consider these examples from a “naïve” point-of-view, we encounter many interesting interpretations. This is the same viewpoint used by students who know little about the chemical principles behind the visual aids, and who do not have a developed understanding of model use. Such an activity to write down a naïve interpretation of pictures and animations and to compare them to research results proved to be a fruitful exercise in teacher training seminars.

It is easy to be distracted into making all our images colorful, attractive and animated. This seems to be the motivation of many Internet sources. But, it is surely more important that the animations should not be misleading.

Acknowledgement

We thank Bill Byers for his critical review on the final manuscript and his helpful remarks.

REFERENCES


Appendix 1. Animations on the Daniell cell from the internet; last access (20 June 2008)


2. www.ltam.lu/chimie/DaniellElementCD.html

3. www.mhhe.com/physsci/chemistry/essentialchemistry/flash/galvan5.swf


